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TASKS OF AIR FLOW RESEARCH

By L. Prandtl

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By L. Prandtl.

I was requested by the Kaiser Wilhelm Society to set forth the tasks of air flow research to which the institute to be inaugurated today is to be dedicated. I will comply with this request in the present address. First, however, I wish briefly to recall those to whom the institute owes its origin.

The first name to be mentioned is that of the great organizer of the Göttingen mathematical and physical departments, Dr. Felix Klein, to whom all Göttingen institutes of applied sciences revert. Our institute is very closely associated with Dr. Klein, I will soon proceed to show you. I had hoped to be able to return my especial thanks to Dr. Klein on this occasion for all that he has enabled me to accomplish here and for what I owe him otherwise, and I feel sure that you would have gladly joined with me in these thanks. As you all know, however, we committed him three weeks ago to his final resting place. In the wish to honor his memory, I have had Dr. Klein's picture brought here, where it will always occupy a place of honor.

* "Aufgaben der Strömungsforschung," a lecture delivered at the dedication of the new buildings of the Kaiser Wilhelm Institute for Air Flow Research, July 16, 1925. Reprinted from "Die Naturwissenschaften," Vol. XIV, pp. 355-358.

In portraying the activity of Dr. Klein on behalf of the institute, I wish first to emphasize the fact that it was his idea alone to create a place in Göttingen for the application of the exact sciences and that his plans met with violent opposition from both within and without. Had it not been for Dr. Klein, I myself (originally an engineer) would not have come to Göttingen. Dr. Klein vigorously inaugurated the threefold development which resulted in the establishment of this institute. Its real history began in 1906, with the inauguration of the "Motorluftschiff-Studiengesellschaft" (Airship Study Society), by Althoff and Rathenau, senior. This society assembled a comprehensive technical faculty, which included, according to the arrangement between Klein and Althoff, three Göttingen men, Klein, Wiechert and myself. Klein had charge of the dynamic group and assigned the tasks in this group. He had made up his mind that Göttingen must participate intensively in aeronautic research and accordingly assigned me the task of suggesting what my specialty (the science of flow) might do for airship flight. I suggested a wind tunnel for experimenting with models of airships and airplanes and soon received the means for the preliminary preparations. Half a year later I had the plans ready and, on Dr. Klein's recommendation, the requisite funds, 20,000 marks, were appropriated and the construction begun. By solicitation in various quarters, Dr. Klein also succeeded in obtaining the means for paying the operating expenses. The small tunnel which, after the dissolution of the "Motorluftschiff-Studiengesellschaft," passed into the possession of the Göttingen University, was thus enabled to carry on a very useful activity until 1918, when its use was discontinued.

In the meantime, the "Kaiser Wilhelm Gesellschaft zur Förderung der Wissenschaften" (K. W. Society for the Promotion of the Sciences) had been founded by Von Harnack. It was now a genuine Klein idea, considering the large funds at the disposal of the new society, to conclude that Göttingen should have a portion of these funds. I received the commission to prepare a memorial on a "Research Institute for Hydrodynamics and Aerodynamics." I carried out my commission to the best of my ability, but without much confidence in the success of what seemed to me a rather bold plan. That this contribution and a subsequent one going more into details found favor with the Kaiser Wilhelm Society, I am indebted to another man, Henry Th. Von Böttinger, who helped the cause along in the senate of the society. He had been very closely associated with Dr. Klein as the first president of the "Gottinger Vereinigung zur Förderung der angewandten Physik und Mathematik" (Göttingen Association for the Promotion of Applied Physics and Mathematics). This association consisted half of leading manufacturers and half of Göttingen professors, the most important thing about it being not the money furnished by the manufacturers, but the personal friendship between the representatives of science and the representatives of practical production. Böttinger had, moreover, acquired a valuable piece of land in Göttingen with the expressed purpose of making it available for the erection of institute buildings. He subsequently donated the land to the Aerodynamic Institute, of whose board of managers he was the first president. His heirs gave the Kaiser Wilhelm Society not only this land for the new institute, but also considerable other land for additional buildings.

Due to Von Böttinger's assistance, there were good prospects in the summer of 1914 of an early realization of the research institute, when the breaking out of the war shattered all our plans. Again it was Dr. Klein who, in the beginning of 1915, showed me a new way for obtaining the militarily important portion of the institute, the wind tunnel, through the aid of the War Department. Böttinger had again contributed much to the realization of this plan and the Kaiser Wilhelm Society, of which I was already a member, took the institute under its wings.

I still have to report the last phase of development, which resulted in these new buildings. Due to the unfortunate conditions after the war, it seemed as if the Aerodynamic Institute would not be supplemented by the other portions of the previously planned institute. I accordingly decided, on receiving a call to a very important professorship in the Munich Technical High School, to accept the position, since I knew that I would be leaving the Göttingen institute in good hands in the person of my faithful assistant, Dr. Betz, though for myself I anticipated more important tasks in Munich than what remained for me in Göttingen. To my great surprise, I was then offered (at a time when elsewhere the most important work had to be suspended for lack of funds) the charge of the new institute, and was thus enabled to change my previous decision to go to Munich. I know what difficult and often seemingly vain endeavors were required to persuafe the authorities, in such hard times, to provide the not inconsiderable means, and I wish to express my heartiest thanks to all contributors and especially to one particular benefactor for the help which has enabled the successful accomplishment of our plans.

If we now compare the finished institute with the plans of 1912, we find that the part built during the war was about three times as large as the peace-time plans, while the new plant has undergone considerable contraction. We will be grateful, however, for what we now have and we will doubtless be able to accomplish much with the smaller institute.

I now come to the tasks of the Institute. It is dedicated first of all to the systematic study of the phenomena of flow in contradistinction from other institutes, which investigate particular technical problems. In order to define better the field of our researches, I must say a few words regarding the physical properties of fluids. These are, so far as we are now concerned, density, viscosity and compressibility. Density, measured by the mass contained in a unit volume, can thereby be considered as known. Viscosity, also known as internal friction, may be illustrated simply by stating that thick oil or liquid glue are examples of very viscous fluids and that water and (still more) alcohol and gasoline are examples of very slightly viscous fluids. Compressibility denotes behavior under varying pressure, both increasing and decreasing. Air is relatively very compressible. It diminishes in volume somewhat less than 10%, when the pressure, to which it is subjected at the normal atmospheric pressure, is increased 10%. With water, which is commonly regarded as incompressible, such changes in volume are also possible, but require about 2000 atm. Moreover, air will flow as a practically incompressible fluid, so long as the pressure differences are small in comparison with 0.1. Such is the case when the velocity is small in comparison with the velocity of sound.

In water, a pressure reduction nearly to a vacuum causes the separation of the air and the formation of vapor bubbles, which then, with an increase in pressure, collapse with a great noise connected with disturbances in the solid bodies in contact with the water. This phenomenon is called cavitation (vacuum formation).

It may be seen how manifold are the phenomena to be investigated in fluid flow from the fact that, in one and the same arrangement of solid bodies between which or around which the flow takes place, the flow changes its character whenever there is any change in the viscosity or compressibility. About 40 years ago Osborne Reynolds found that, in so afr as compressibility played no part, it depended on the ratio of the inertia effects to the viscosity effects, which can be represented by the pure number

$$\frac{\text{length} \times \text{velocity} \times \text{density}}{\text{viscosity}}.$$

If this number (which is called "Reynolds number" in his honor) is the same in two comparable cases (for example, the motion of a sphere in air and of another sphere in water), the flowing motions are also exactly comparable, but otherwise not. (The composition of Reynolds number shows that small dimensions and small velocities produce the same effect as great viscosity and conversely.) From what has been said, you can understand what is meant by the statement that every flow process must be followed through all the Reynolds numbers. As regards the resistance offered by a sphere, for example, moving in a fluid, this work has been performed for Reynolds numbers 1 to 1,000,000, demonstrating the existence of four or five essentially different laws, according to the magnitude of the Reynolds number. The forms of flow corresponding to these resistances are still to be investigated, for only through these can we understand the observed laws.

When we think of all the possible bodies to be tested, the necessary number of experiments is enormous. We will naturally therefore attempt to test only bodies of technical importance, such as spheres, cylinders and rotational bodies and, above all, airplane wings and propeller and turbine blades. On account of the high velocities often occurring in practice, which, in air, may even attain or exceed the velocity of sound and, in water, reach the cavitation limit, the same velocities must be produced in the laboratory.

Thus far I have spoken only of bodies moving in fluids. The same principles apply, however, to fluids flowing in tubes or tanks. The resistances and forms of flow in straight and crooked tubes and in branch tubes and around obstacles must likewise be systematically investigated. The processes in revolving machines also come in, at least in principle. Furthermore, we are interested in free-fluid flow and in the various motions of free-fluid surfaces, wave formations, etc., as also the flow processes in natural and artificial water currents, in which the eroding of the stream bottom by the water and the continuous reformation of the stream bed from the transported particles afford many more problems for solution. Also the flow processes in free air come within the scope of our investigations. Lastly, we must not forget the application of the principles of flow to living organisms. The locomotion of water animals, from the cilia-propelled infusoria to the swift dolphins, and of flying animals, from the diminutive gnat to the mighty eagle, demonstrates that quite different conditions obtain at small Reynolds numbers than at large ones. An experiment with an enlarged model of an infusorium according to Reynolds law is entirely possible. It is only necessary to place the model in a very viscous fluid and to move it very slowly.

As regards the new institute, it is our purpose to make the most of our limited means. The two vacuum chambers, of about 10 m^3 (353 cu.ft.) capacity, can be used in various ways. The air can first be pumped out and then atmospheric air, entering through a tube, can be allowed to refill them in a few seconds. We thus obtain, for a short time, an air stream of ample cross section and high velocity, in which we can perform resistance experiments and the like. When combined with a 20 m^3 (706 cu. ft.) gasometer, they can be used for calibrating nozzles and other devices for measuring quantities of air. Both chambers can, moreover, be filled with compressed air by means of a compressor, so that experiments can then be performed in the outflowing compressed air. Furthermore, one chamber can be filled with compressed air and the other with water and the water can then be forced out by the compressed air, whereby, for a short time, just as great Reynolds numbers can be attained as would otherwise be possible only with very powerful pumps. We also have a rotary pump, which works in the water chamber. By pumping the air out of the chamber the pressure can be lowered so that cavitation occurs in the by-pass tube used for the experiments. In case of need, the pressure in the by-pass tube can be increased by the introduction of pressure into the water chamber, for comparative experiments without cavitation. The pump can also work in an open trough, and thus affords the possibility of experiments similar to those performed in a hydrodynamic laboratory. The trough serves also as a towing tank for resistance experiments. This finishes the list of the already completed experimental devices.

More tanks are yet to be built, chiefly for photographing every kind of flow; several blowers for generating air currents in tubes and tunnels and also as objects of research in themselves; and, lastly, a revolving room, in which experiments can be performed on rotating objects by observers rotating with them. Thereby, aside from the tasks of turbine designing (investigation of a single rotating passage between two blades), meteorology, with the theories of which we have already been busy, will also receive experimental attention. The revolution of the earth exerts a decisive influence on the winds. Such winds can be reproduced to a certain degree in the rotating chamber.

Aside from the vacuum plant and the rotating chamber, the laboratory devices are not of themselves entirely new. Many of the experiments have been previously performed on a smaller scale in my present laboratory for applied mechanics, so that we have already acquired experience in many a field and know approximately what to look for. I expect, therefore, from the new laboratory, less sensational discoveries, but rather a thorough systematic investigation of the whole field, for the benefit of the industries interested in our field of work and hence also for the common welfare.

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.